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THERMOSTABILITY IN TEXTILE FABRICS

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ABSTRACT: Thermal transmission through the textile fabric is one of characteristics, which influence thermo-physiological comfort while wearing the clothing. Measuring of thermal transmitting through textile fabrics is performed by various methods and devices. This report informs about knowledge and experience with measuring these characteristics. It discusses available technical instruments for measuring of thermal transmission in accredited laboratory. Measured thermal characteristics are compared to theoretical calculation of thermal transmission through textile fabrics.

KEY WORDS: thermodegradation, thermo-stability, web thickness, thermal flow, thermal conductivity

1. INTRODUCTION

Thermodynamics as a branch of physics deals with energetic changes of systems evoked by changes of external or internal conditions (thermal, pressure, composition etc.). Observed changes are realized in specified field. We distinguish three kinds of systems: isolated, open, closed. Textile clothing is a part of closed system organism-, clothing- environment in which thermal transmission runs. Thermal energy, as an inside energy, comes from warmer object to colder, i.e. from organism to external environment through textile fabrics (in extreme conditions it can be also vice-versa). Thermal transmission from organism to environment through clothing is realized by conduction (flowing) and radiation. When the thermal is transmitted by conduction, the energy is spread vertically from organism to external environment through clothing. Thermal transmission with radiation is realized by electromagnetic waves from thermal radiant (thermaling medium). Smaller changes of thermal transmission are realized with devaporation, devaporation with breathing, air thermaling while breathing, see Fig.1.

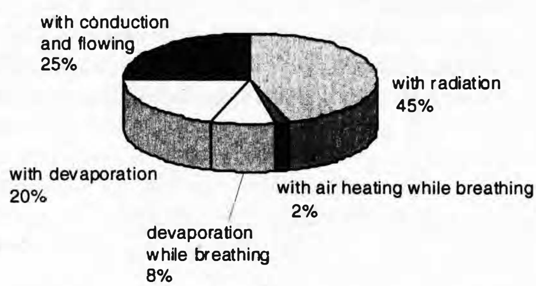

Fig. 1: Scheme of thermal loss of organism

Chemical thermodynamics deals with chemical reactions connected to consumption or energy-thermal releasing. Transition of system from one to the other state is called thermodynamic action and it can be run as a reversible or irreversible action. From the thermochemic point of view, there are changes of textile material structure affected by thermal difficulty. They influence production technology and utility characteristics of textile fabrics (e.g. thermodegradation, mechanical characteristics, changes of supramolecular structure etc.). Globally we can indicate these characteristics as thermostability.

Thermal characteristics of textile materials are described as temperature of vitrification, softening, melting, decomposition or flammability of textile material. According to thermal balance, we can denote the reactions of textile materials as exotermic actions (textile fabrics release the thermal to the surroundings), and endothermal (textile fabrics absorb the thermal).

Finally, when we evaluate the thermal characteristics of textile fabrics, laboratory devices work according to principles of thermodynamic systems and their thermochemic changes are partly known physical quantities.

2. THERMAL CHARACTERISTICS OF TEXTILE FABRICS

We can evaluate thermal comfort which offers clothing the help of various devices, as one which clearly characterises particular physical action. Devices simulate conditions of thermal activity in the system of organism-, clothing- environment. Thermal activity is measured in the conditions close to regime of human organism.

2.1 Measuring of thermal characteristics with Alambeta device

This is indirect method of measuring in which short-term thermal contact between moist skin and dry textile fabric is stimulated and objectively evaluated. The model of moist human skin is substituted with textile knitting COOLMAX-FX 205, which is damped with 1 ml fusion with impurity of detergent 1:50.

2.1.1 Measured values:

a./ material thickness h (mm)

b./ thermal flow q (H) (W.m^2) gives us thermal amount flowing from skin with temperature t_2 into textile fabric and with temperature t_1 to unit of time.

$$q = b\frac{t_2 - t_1}{\sqrt{\pi.\tau}} \qquad (1)$$

c./ measuring of thermal conductivity λ (W.m^{-1}.K^{-1}) gives us the speed of thermal transmission through textile fabric, e.g. amount of thermal that transmits the unit of length within the unit of time and creates the difference 1 K. In physics this is denoted as coefficient of thermal conductivity λ.

d./ measuring of thermal capacity c (J.kg^{-1}.K^{-1}) is expressed by measuring the thermal within constant pressure

$$c = \frac{\Delta Q}{\Delta t} \qquad (2)$$

e./ thermal absorptive capacity b (W.m^{-2}.s$^{1/2}$.K^{-1}) is a parameter which characterizes thermal sensing and thermal amount, and which flows with the difference of temperatures 1 K through the unit of surface within the unit of time as a result of thermal accumulation in unit's volume.

$$b = \sqrt{\lambda.\rho.c} \qquad (3)$$

f./ surface resistance of thermal conductory r (W^{-1}.K.m^2) is in physics so called coefficient of thermal transmission α.

$$r = \frac{h}{\lambda} \qquad (4)$$

g./ measuring of thermal conductivity a (m^2.s^{-1}) expresses material ability to compensate temperature.

$$a = \frac{\lambda}{c.\rho} \qquad (5)$$

h./ rate of maximal and stabilized flow p

$$p = \frac{q_{max}}{q_v} \qquad (6)$$

i./ count measured - n (5...20)

2.2 Measuring of thermal characteristics on device P-test

Principle of measuring and evaluating of results with the help of this device is approaching the norm ISO 11092, but it is more easily and economically more accessible. The object of exam is to measure the thermal flow q running over the surface of thermal model of human skin and textile fabric. It is possible to use following devices for measuring:

- thermal resistance of textile fabric with the stable temperature of 32 °C
- evaporative resistance and vapour permeability textile fabrics in izotemic and anizotemic conditions. Microcomputer installed in device enables us to choose starting parameters of head temperature, air speed in measuring canal and degree of measuring head moisturing. Measured data are evaluated with micro – computer and displayed on the screen of device]

2.2.1 Measured indicators

a./ relative vapour permeability for water vapours p (%) which is unnormalized quantity, where 100 % permeability is thermal flow q_0 evoked with devaporation from free water surface with the same average as one of the sample pieces. Thermal flow will be decreased to the value q_v by covering the surface with measured sample.

$$p = 100\left(\frac{q_v}{q_0}\right) \tag{7}$$

b./ evaporative resistance R_{et} ($m^2.Pa.W^{-1}$). Partial tension of water vapour in the air P_a is a quantity, which is defined from relative moisture of air φ and its temperature t_a. Partial vapour tension in the saturated state P_m is a function of air temperature programmed in the computer of the device

$$R_{et} = (P_m - P_a)(q_v - q_o) \tag{8}$$

c./ thermal resistance R_{ct} characterizes resistance to thermal transmission through sample with defined temperature t_m of its one side and when the thermal is transmitted through convention from its second side into air with temperature t_a, the thermal resistance of this external marginal layer is substracted.

$$R_{ct} = (t_m - t_a)(q_v - q_o) \tag{9}$$

2.3 Measuring of thermal characteristics on device Togmeter

Device is placed in the box with controlled air flow. Inside the box, between warm and cold board, we placed experimental sample and after achievement of stable state three thermal gradients were scanned with thermal sensitive elements. The result of an exâm is enumeration of thermal resistance from thermal gradients,

2.3.1 Measured indicators

– thermal resistance of experimental sample ($W^{-1}.K.m^2$)

$$R_f = \left(\frac{T_2' - T_3'}{T_1' - T_2'}\right) - \left(\frac{T_2 - T_3}{T_1 - T_2}\right) R_S \tag{10}$$

T_1, T_2, T_3 – sensitive element temperatures without experimental sample; T_1', T_2', T_3' – sensitive element temperatures with experimental sample; R_S – thermal resistance of standards 0.112 $W^{-1}.K.m^2$

3. EXPERIMENTAL PARTS

For consideration of measurement of existing ways of thermal characteristics, we have made the measurements on three mentioned devices. The measurements were made on:

a./ 100 % unbleached cotton fabric
b./ 100 % coloured polypropylene fabric

The measurement results are shown in table 1-3. Tables show measured values, which can be compared but not all measured indicators.

3.1 Measurement results on device Alambete

Note: value of surface resistance of thermal conductivity r measured on Alambete is identical with the value of thermal resistance Rf measured on Togmetr.

Tab. 1: Average values of thermal conductivity λ ($W.m^{-1}.K^{-1}$), thickness h (mm) and surface resistance of thermal conductivity r ($W^{-1}.K.m^2$) from 20 measurements measured with air temperature of 22 °C and relative air humidity of 41 %

Indicators	**Cotton fabric**	**Polypropylene fabric**
Middle value of measured thermal conductivity (λ)	0.0633	0.0691
Decisive deviation of measured thermal conductivity (λ)	0.008	0.005
Interval of reliability for middle value (λ)	0.0670 - 0.0596	0.0699 - 0.0674
Middle value of fabric thickness (h)	0.548	0.697
Middle value of surface resistance of thermal conductivity (r)	0.0087	0.0115

3.2 Measurement results on device P-tester

Tab. 2: Average values of evaporative resistance Ret ($m^2Pa.W^{-1}$) from 20 measurements measured at air speed of 3 $m.s^{-1}$, air temperature of 23 °C and relative air humidity of 40 %

Indicators	**Cotton fabric**	**Polypropylene fabric**
Middle value of evaporative resistance (Ret)	4.295	4.115
Decisive deviation of evaporative resistance (Ret)	0.787	0.5331
interval of reliability for middle value (Ret)	4.662 - 3.928	4.3637 - 3.8663

Calculating thermal conductivity (λ):

$$\lambda = \frac{h}{R_{et}} \tag{11}$$

$$\lambda_{ba} = \frac{0,548}{4,295} = 0,1276\left[W.m^{-1}.K^{-1}\right] \qquad \lambda_{pop} = \frac{0,697}{4,115} = 0,1674 \text{ W.m}^{-1}.\text{K}^{-1}$$

3.3 Measurement results from device Togmeter

Tab. 3: Average values of thermal resistance R_{et} ($m^2.K.W^{-1}$) measured on surface of 20 cm^2, at air pressure of 6.91 Pa, amount of measurements n = 3

Indicators	**Cotton fabric**	**Polypropylene fabric**
Middle value of thermal resistance (Rf)	0.0041	0.009
Middle value of fabric thickness (h)	2.03	2.01

Calculating of measuring thermal conductivity (λ):

$$\lambda = \frac{h}{R_{et}} \tag{12}$$

$$\lambda_{ba} = \frac{2,03.10^{-3}}{0,0041} = 0,495 \text{ W.m}^{-1}.\text{K}^{-1} \qquad \lambda_{pop} = \frac{2.01.10^{-3}}{0,009} = 0,223 \text{ W.m}^{-1}.\text{K}^{-1}$$

Note: Since fabric thickness measured on device togmeter was measured with lower value of pressure than was the set norm of fabric thickness measuring, it is possible to use measurement of fabric thickness from device Alambeta when we are counting:

$$\lambda_{ba} = \frac{0,548.10^{-3}}{0,0041} = 0,1337 \text{ W.m}^{-1}.\text{K}^{-1} \qquad \lambda_{pop} = \frac{0,697.10^{-3}}{0,009} = 0,0774 \text{ W.m}^{-1}.\text{K}^{-1}$$

3.4 Evaluation of measurement results

Tab. 4: Total table of common indicators of thermal conductivity (λ)

Indicators of measuring thermal conductivity (λ)	**Cotton fabric**	**Polypropylene fabric**
Device Alambeta	0.0633	0.0691
Device P - tester	0.1276	0.1674

For consideration, Tab. 5 shows the values of thermal conductivity of various kinds of materials. Values of thermal conductivity measured on devices should be in accordance with thermal conductivity of cellulose and polypropylene.

Tab. 5: The values of thermal conductivity of various kinds of materials

Indicators of thermal conductivity of thermal insulators	**λ ($W.m^{-1}.K^{-1}$)**
Wood	0.17
Asbestos	0.17
Plastics	0.17
Leather	0.15
Polystyrene	0.1329
Polyakrylonitrile fibres	0.05
Nylon	0.209 - 0.337
Polypropylene fibres	0.22 - 0.30
Cellulose	0.11
Air	0.0244

3.5 Theoretical calculation of thermal conductivity

Fabric structure consists of binding points and air openings between these binding points. If we know the correct volume of fabric porosity P_V (cotton – 0.5514, polypropylene 0.6222) and thermal conductivity of cotton, polypropylene and air (λ cellulose – 0.11 $W.m^{-1}.K^{-1}$ a **λ polypropylene** – 0.22 - 0.30 $W.m^{-1}.K^{-1}$, λ air – 0.11 $W.m^{-1}.K^{-1}$) we can enumerate the thermal fabric conductivity in this way:

$$\lambda_{ba.} = (1 - P_v).\lambda_{ba} + P_v.\lambda air \qquad (12)$$

$$\lambda_{ba.} = (1 - 0{,}5514).0{,}11 + 0{,}5514.0{,}024 = 0{,}0626 W.m^{-1}.K^{-1} \qquad (12)$$

$$\lambda_{POP.} = (1 - 0{,}6222).0{,}22 + 0{,}6222.0{,}024 = 0{,}0981 W.m^{-1}.K^{-1} \qquad (12)$$

It is clear from calculated theoretical indicators of thermal conductivity, that values measured with device Alambeta are the most similar to theoretical measurements of cotton sample. With regard to polypropylene sample, the theoretical value is approaching the most to the value measured on device P-tester.

4. CONCLUSION

The aim of this report was to evaluate some of the methods of measurement of thermo-physiological characteristics of textile materials. It is clear from the measurement, that there is considerable difference in the results of measurement performed by described methods. Measurement method contucted with the help of device Togmeter is different that the measurement principle. The measurement is time-consuming and requires strict climatized conditions. The producer recommends the use of the device mainly for measurements of fabrics with average and bigger surface weight. On the other hand, measurement with the use of P-tester is fast and with the possibility of statistic evaluation through PC connection. Device Alambeta is convenient because of capability of measurement and evaluation of various thermal quantities. At the end we can say, that this field of measurements is still open and will be the subject of further searching for other methods, which are more suitable for measurement of these variable characteristics.

5. REFERENCES

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